DOCUMENT RESUME

ED 222 540 TM 820 692

AUTHOR Weitzman, Donald O.
TITLE Individual Differences in Spatial Memory: Thinking Backwards.
PUB DATE Nov 81
NOTE 26p.; Paper presented at the Annual Meeting of the Psychonomic Society (22nd, Philadelphia, PA, November 12-14, 1981).

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Adults; Cognitive Processes; *Cognitive Style; *Individual Differences; *Memory; *Physical Environment; *Spatial Ability
IDENTIFIERS Analogical Reasoning; Sequential Memory

ABSTRACT

The study was designed to evaluate a hypothesis derived from recent trends in cognitive theory. The hypothesis concerned whether spatial environment information stored in memory is primarily analog or propositional. A related question concerned whether differences between analog and propositional processes underlie individual differences in the ability of adults to accurately represent and recall information about their spatial environment. Experiments were conducted to determine whether subjects differ with respect to emphasizing either analog or sequential processes in a test of spatial recall. The study indicated individual differences in performing spatial judgments were partially based on the differences in strategies people adopt in acquiring and utilizing spatial information. The results were consistent with the belief that some people are superior in maneuvering in their environment because they have survey knowledge of it and operate on that knowledge from memory. The first experiment indicated that when spatially unskilled subjects were provided explicit instructions to adopt an imagery strategy or were given a perceptual display of the task, their performance approximated the spatially skilled subjects. The imagery system seemed to be trainable. The implications of the experiments are that individual differences in strategy selection cannot be ignored in theories of spatial cognition. (DWH)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED222540

INDIVIDUAL DIFFERENCES IN SPATIAL MEMORY: THINKING BACKWARDS

Donald O. Weitzman*

Army Research Institute

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☒ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

D. O. Weitzman

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

Paper presented at the twenty second meeting of the Psychonomic Society: November, 1981

* Now at Bell Laboratories, Whippany, New Jersey 07981

TM 820 052

The ability of individuals to acquire knowledge about where things are in their environment and how to get there is a basic requirement both for everyday environmental behavior and for human survival. Consider, for example, the plight of the foot soldier confronted with the task of finding his way from one location to another across unfamiliar terrain. In many field contexts it would be impossible for this individual to consult a map at each decision point to select the shortest or most navigable route. In other time - critical situations, the soldier may be forced to select an alternate route or to reorient himself by adopting a different perspective with respect to his mental map. In both situations, the soldier must rely on his memory of the geography of his surroundings.

Although many researchers have investigated issues related to how we acquire, store, and retrieve knowledge from the environment (Lynch, 1960; Down and Stea, 1973; Siegel and White, 1975; Allen, Siegel and Rosinski, 1978), they have often failed to consider individual differences among learners. This is difficult to justify; people are notoriously variable in their ability to acquire and make use of knowlege about their spatial environments. Kozlowski and Bryant (1977) have shown, in a simple but impressive series of experiments, substantial individual differences in estimating the directions of objects and places outside one's immediate field of view. This ability to point in a given direction correlated about .50 with their response to a single question, "How good is your sense of direction?" Perhaps the best evidence for large individual differences in the ability to store and retrieve spatial information comes from Thorndyke and Stasz (1980). They describe a series of experiments where subjects were asked to memorize a map rich in detail and afterward, to draw (or more accurately recall) as much of the map as they could. Mental processes in the form of higher - order strategies were shown to provide a basis for differentiating individual performance in the map memory task. While it seems clear that people show substantial differences in their ability to acquire spatial knowledge of their environment it is still by no means certain how these differences should be characterized at the level of cognitive processes.

The present study was designed to test some hypotheses arising from some recent trends in cognitive theory. One hypothesis of interest concerns whether spatial information

stored in memory is primarily analog or propositional[1]. A second related question has to do with whether differences between analog and propositional processes underlie individual differences in the ability of adults to accurately represent and recall information about their spatial environment.

There are data available to support both propositional and analog accounts of spatial representation. One set of studies suggests that we keep track of the location of objects around us by storing location information sequentially or in lists based on abstract descriptions (Anderson and Bower, 1973). Thus, location memory would depend primarily on the use of sequential search strategies. In contrast, the analog account maintains that the cognitive representation of location information resembles in some rough isomorphic way, the experience of seeing the actual physical environment; that is, we can visually image the spatial environment and mentally scan for the location of objects in it. This suggests that location information is available to us simultaneously (or in, parallel) and spatial recall would depend upon mentally scanning across visual images[2]. The experiment reported below investigate such cognitive processes in spatial memory using the technique of backward recall.

The present experiments were concerned with whether subjects, selected on the basis of being very good or very bad at judging the relative location of landmarks in a highly familiar environment, differ with respect to emphasizing either analog or sequential processes in a test of spatial recall. If subjects use a retrieval process analogous to scanning a visual image, then one might expect that backward recall (estimating, for example, the direction of unseen objects along a route from the end of the route) should be as simple as forward recall.

---

[1] Some examples of current debate are to be found in Anderson, 1978; Kosslyn and Pomerantz, 1977 and Pylyshyn, 1973.

[2] See studies by Cooper and Shepard, 1973 and Kosslyn, 1973, 1975 for experimental examples of such analog processes in spatial memory.

On the other hand, if subjects use sequential strategies, one might expect that backward recall would be more difficult since subjects must change the form of their representation to produce accurate estimates of direction. The following two experiments simply apply this experimental logic to the investigation of individual differences in judging the direction or orientation of unseen objects experienced in a route walking task and in judging spatial position in a haptically presented spatial display.

Experiment 1

Subjects

In this study 20 subjects were selected from a pool of 81 Army Noncommissioned Officers (NCOs). Two separate groups of 10 subjects were formed on the basis of their accuracy on a spatial orientation task and on their performance on a map completion task. The orientation task required that subjects imagine standing behind a certain building located on Fort Belvoir, Virginia (their duty station) and to be facing in a given direction. Subjects then had to estimate from memory the direction of 8 familiar buildings on Fort Belvoir. The map completion task simply required subjects to mark the precise location of 5 other familiar buildings on an incomplete map of Fort Belvoir. Performance was measured in terms of Euclidean accuracy; that is, the distance in mm that each building was displaced from its actual location. It was the 10 highest and 10 lowest scorers on both tasks (even though the correlation between both was .67) who formed the two experimental groups, heretofore labled as spatially skilled (SS) or spatially unskilled (SU). Mean angular error for SS and SU NCOs was, in order, 13.5° (SD = 6.8) and 40.7° (SD = 14.1), $t(18) = 3.33$, $p < .01$; map performance was, in order, 11.3 mm (SD = 3.4) and 29.6 mm (SD = 7.5), $t(18) = 6.68$, $p < .01$. Subjects, drawn from a relatively homogenous pool, were reasonably matched in terms of age (31.2 vs. 33.5 years), number of months at Fort Belvoir (18 vs. 23 months) and intelligence (107 vs. 112 AFQT).

Procedures

The experiment was carried out in a maze of hallways located on the second floor of the Defense Mapping Agency at

Fort Belvoir. Six different routes through this human sized maze were used to manipulate both the length and complexity of the paths, as illustrated in Figure 1. The hallways contained numerous offices and doorways, interconnecting corridors, and several easily discriminable target locations (i.e., 3' x 5' posters) placed along the route (indicated by hatch marks in Figure 1). The subject's task was to first walk along the route and then estimate to the nearest degree the direction of each target location from either the start (forward recall) or end (backward recall) of the route. An additional feature of the experiment was to examine the utilization of prior knowledge about type of recall for the two groups of subjects. In the precued condition, the experimenter explicity indicated the type of recall that would be required (forward or backward) before each route walk. In the postcued condition, the experimenter indicated the type of recall after each subject completed the walk.

Subjects walked along the route in groups of five, with half the subjects beginning at one starting point and half at the other. After completing the walk, subjects were taken to a waiting room, located near the end of the route. The experimenter then took each subject separately to either the start or end of the route. The experimenter provided a compass rose composed of 72 numbered arrows. The subject's task was to face in the direction of the last leg of the route (0 degrees) and mark on the compass rose the arrow which pointed directly to each target location. This procedure was repeated 12 times (three in each of the experimental conditions: postcued forward, postcued backward, precued forward, precued backward). The repetitions were in random order. Subjects were tested on one route per day beginning with the least difficult and finishing with the most difficult route. Routes of different lengths were presented in counterbalanced order across subjects.

Result and Discussion

Figure 2 shows the mean angular error in forward and backward recall for the two groups. The data for the three pairs of route distances are combined in Figure 2 since the distance variable did not prove to be significant. A four-factor analysis of variance was carried out with groups (SS, SU), recall type (forward, backward), cueing

condition (pre, post) and route complexity (4, 8, 13 turns) as variables. The four main effects were all significant ($\rho < .01$) as were the interactions between groups x recall type, groups x cueing conditions and groups x recall type x cueing conditions. Of special interest was that SS subjects backward recall was, for all practical purposes, indistinguishable from forward recall with the exception of the most complex route. On the other hand, SU subjects judged orientations less accurately in backward recall under all conditions ($\rho < .01$ for the interaction between groups and recall type). This result provides strong support that the SS subjects can recall the orientation of the target locations using a search strategy that visually scans across the route whereas the SU subjects may have relied on the sequential nature of the stimulus inputs (if one accepts the experimental logic of the backward recall technique). Figure 2 also shows that with more complex routes, backward recall proved to be more difficult for both groups. This result appears to be accountable, at least in part, on the basis that increasing route complexity simply overwhelmed the capacity of the visual imagery system with an increasing need for subjects to rely on sequential strategies.

A further breakdown of the data in terms of cueing conditions is shown in Figure 3. For both groups precueing significantly improved performance under any conditions ($\rho < .01$) although the beneficial effects of precueing were most evident in the SS group ($\rho < .01$ for the interaction between groups and cueing conditions). As Figure 3 also shows, precueing benefited backward recall more than foward recall for the SS group but not for the SU group ($\rho < .05$ for the interaction between groups, recall type and cueing condition). These results presumably reflect the advantage that prior information has in providing for some form of strategy preparation. The fact that SS subjects benefit more from precueing suggests that the spatially skilled may have greater facility in adopting different strategies, enabling them to exploit prior information to greater advantage.

It is possible that SU subjects may suffer in tests of spatial memory simply because they are not aware of the appropriate strategies to use. To test this hypothesis, the two poorest subjects were provided with two different sets of instructions in separate studies using a single eight turn route. In the first case, subjects were

encouraged to form a mental picture of the route and to use this (imagery) strategy in following the route and in making orientation judgments. In the second case, a perceptual analog of the imagery process was provided by giving subjects on the first trial, a schematic map of the route with the target locations marked on it (such as in Figure 1). As before, they were to indicate from memory the direction of the four locations from either the beginning or end of the route.

Orientation judgments under the two instructional conditions are compared with previous performance (self-instruction) in Figure 4. Although only two cases are reported, it appears that the type of strategy presumably adopted strongly affected the accuracy of the orientation estimates. Particularly striking is the improvement seen in backward recall. In fact, when subjects were given an explicit map of the route, they produced results remarkably similar to those found for the spatially skilled subjects (see Figure 2). These results appear to imply that SS subjects do indeed recall spatial information by a process similar to visual perception; that is, they acquire a quasi-visual representation of the route and scan this representation (or cognitive map) as they would visual data to estimate orientation. These results further suggest that subjects who are unable to spontaneously adopt an appropriate strategy in spatial recall can modify their strategy given the appropriate instructional set.

Experiment 2

The second experiment was designed to provide a laboratory analog of the events assumed to occur in Experiment 1. Experiment 2 investigated whether similar results would be obtained in a haptically presented spatial display.[1]

---

[1] Experiment 2 was adapted from an experiment that Millar (1975) conducted with blind and sighted children in a test of their spatial memory. Portions of these results were presented at the American Psychological Association Annual Convention, New York, September, 1979.

Subjects

There were 40 subjects. They consisted of the 20 NCOs used in Experiment 1 and 20 students selected from a pool of 44 undergraduate and graduate students on the same basis as the NCOs; that is, on the basis of being very good or very bad at making orientation judgments of familiar landmarks in a large scale space (the mall area in Washington, D.C.) and in a map completion task of the same area. Mean pointing error for the spatially skilled (SS) and unskilled (SU) students were, in order, 22.8° (S.D. = 9.4) and 49.0° (S.D. = 19.5), $t(18) = 2.79$, $p<.02$; map performance was, in order, 38 mm (S.D. = 8.9) and 56 mm (S.D. = 11.8), $t(18) = 8.18$ $p<.01$. In the SS student group there were seven men and three women (mean age, 23 years) and in the SU student group there were six men and four women (mean age, 22 years).

Procedure

The spatial display consisted of a 150 x 1 cm slot that formed an 8-sided spatial layout with 7 turns (see Figure 5). For training, subjects held a stylus and traced along the slot to a prepared stop (or spatial position) without being able to see the display. The stop was removed after contact and the subject continued tracing the slot to the end. The recall task was to trace the slot with the stylus either from the start (forward recall) or from the end of the slot (backward recall) to the position where the stop had been ecnountered during presentation. After recall, the stop was replaced for the next training trial.

Two spatial positions, one near the starting point (26 cm) and one far from it (124 cm) were tested. Since tracing the display was sequential, the near position represented the primary and the far position a recent stimulus in relation to the serial ordering of the display.

There were two cueing conditions. As before, they differed solely on whether instructions from the type of recall were given prior to a trial or only prior to recall.

Subjects were tested singly. The task was explained to them, and they received two practice trails followed by 32 tests trials (eight in each of the experimental conditions: precued forward, precued backward, postcued forward, postcued backward). The order of experimental conditions were random. The orientation of the display was changed on each trial.

Results and Discussion

Mean absolute error for NCOs and students in each skill group are shown in Figure 6. In separate analyses, the effect of groups (SS vs. SU), $\rho<.01$ for NCOs, $\rho<.001$ for students, and the interaction between groups and recall type, $\rho<.01$ for NCOs, $\rho<.005$ for students, were all significant. Multiple comparisons (Newman-Keuls test) showed that for SU subjects there were significant differences between forward and backward recall, $\rho<.025$ for NCOs, $\rho<.01$ for students, while for the SS subjects there were no differences. The latter finding is consistent with the hypothesis that SS subjects base their estimates of spatial position on a quasi-visual representation of the spatial layout while the SU subjects rely primarily on sequential strategies.

In order to examine more closely the difference in processing strategies adopted by the two skill groups, the data were further analyzed in terms of stimulus position. The mean absolute error for each group of NCOs and students for each spatial position is shown in Figure 7. For the NCOs a significant interaction was found between groups, recall type and spatial position ($\rho<.001$). Multiple comparisons (Newman-Keuls test) showed that for the SS NCOs there were no differences between stimulus positions in either forward or backward recall. For the SU subjects however, stimulus position has a marked effect. A comparison of the differences between recall of the two positions revealed that SU NCOs perform marginally better on the near (or primary) position in forward recall ($\rho<.10$) and considerably better in the far (or recent) position in backward recall ($\rho<.001$). Since time and distance to recall from the start of the trace to recall is least for the far position in backward recall and least for the near position in forward recall this suggests that time and distance was the preferred mode of processing for the spatially unskilled NCOs. This result implies a sequential haptic (touch and movement) rather than a verbal strategy. Unlike the results for the NCOs, the effect of stimulus position was significant ($\rho<.005$) for the students, indicating that the near position produced significantly better performance than the far position. For the SU students the difference between recall of the two positions was greater for forward recall with increased errors in the far (or recent) position and marked improvement on the near (primary) position. On the assumption that the primary effect is mainly due to longer-term verbal encoding

and rehearsal (Atkinson & Shiffrin, 1968), this result implies the SU students used a verbal rehearsal strategy. For the SS students, stimulus position was unaffected by recall type, a result that would be predicted for visual strategies. However, the presence of a primary effect for SS students can be taken as evidence that either a completely visual strategy could not have been used or that imaging of the display occurs from the start of the display during recall. While both explanations are strong possibilities, the present results do not permit choosing with any great confidence.

General Discussion

Evidence that it is possible to identify groups of people who are consistently good or consistently bad at performing spatial judgments has been obtained by Kozlowski and Bryant (1977) who have shown that individual differences in spatial orientation ability is predictable from self-reports of "sense of direction."

The present study goes a step further in indicating that individual differences in performing spatial judgments are based, in part, on the differences in strategies people adopt in acquiring and utilizing spatial information. The results of Experiment 1 and 2 are consistent with the assumption that subjects who are highly skilled at estimating the direction or location of an object in space base their estimates on a quasi-visual search process which permits simultaneous access to location information in memory. On the other hand, subjects who are poor at estimating the location of objects base their estimates on a sequential code of the routes. Emphasis on a visual imagery strategy was inferred for subjects who could produce accurate spatial judgments (as in the orientation task) just as easily backwards as forwards along the routes; emphasis on sequential strategies was inferred for subjects who had difficulty in making accurate spatial judgments when required to think backwards along the routes. It was hypothesized that subjects who adopt a sequential search strategy would have to change perspective on their representation in backward recall and the additional processing would result in less accurate spatial judgments. Moreover, reported strategies tended to support an interpretation based on these processing differences. Taken together, these results are clearly consistent with the view that some people are better than others in getting around in their environment because they have visual (or survey) knowledge of that environment and operate on

that knowledge from memory. While it is tempting to think that this process implies scanning over a picture-like representation, the process itself remains somewhat mysterious. Nevertheless, an image-like scanning process was clearly differentiated from a sequential process in Experiments 1 and 2. It was shown however, that image scanning is capacity limited. Indeed, for SS subjects, backward recall became significantly less accurate than forward recall as route complexity increased, a result which is in the opposite direction from what would be predicted with visual strategies. A reasonable explanation is that maintenance of a precise and detailed visual representation makes a heavy demand on central processing capacity. It is of interest to note that Phillips and Christie (1977) provide evidence which is consistent with the notion that the visual imagery system is heavily dependent on a central processor of limited capacity.

Finally, Experiment 1 indicated that when spatially unskilled subjects are provided explicit instructions to adopt an imagery strategy or are given a perceptual display (or map) of the route, their performance approximated the spatially skilled subjects. As was indicated earlier, a plausible account of this finding is that the imagery system is flexible and therefore trainable. Thus, people are capable of being influenced by instructional methods in the sense that they can reorganize a preferred sequential (or symbolic) mode of processing information into an analog mode when it is reasonable to do so. A similar result has been reported by Hayes-Roth, and Hayes-Roth (1975).

It is evident that how people cognitively represent and process spatial information about their environment has important consequences for how well they can acquire and utilize that spatial knowledge. For the spatial tasks analyzed in this paper, there is compelling evidence that different people mentally represent and process that knowledge in different ways. In the two experiments reported here, people consistently reported different processing strategies which were validated in tests of spatial memory. Several implications follow. One is that individual differences in strategy selection cannot be ignored in theories of spatial cognition. Another is that many studies concerned with the mental processes by which spatial information is recalled and utilized (for a recent review, see Evans, 1980) are likely to produce different results unless strategy selection is restricted or evaluated.

REFERENCES

1. Allen, G., Siegel, A. and Rosinski, R. The role of perceptual context in structuring spatial knowledge. Journal of Experimental Psychology: Human Learning and Memory, 1978, 4, 617-630.

2. Anderson, J. R. and Bower, G. F. Human associative memory, New York: V. H. Winston, 1973.

3. Anderson, J. R. Arguments concerning representations for mental imagery. Psychological Review, 1978, 85, 249-277.

4. Atkinson, R. C. and Shiffrin, R. M. Human memory: a proposed system and its control processes. In K. W. Spence and J. T. Spence, (Eds.), The Psychology of Learning and Motivation (Vol. 2), New York: Academic Press, 1968.

5. Cooper, L. A. and Shephard, R. N. Chronometric studies of the rotation of images. In Chase, W. G. (Ed.) Visual information processing. New York: Academic Press, 1973.

6. Downs, R. and Stea, D. Image and environment. Chicago: Aldine, 1973.

7. Evans, G. W. Environmental Coguition, Psychological Bulletin, 1980, 88, 259-287.

8. Hayes-Roth, B and Hayes-Roth, F. Plasticity in memorial networks. Journal of Verbal Learning and Verbal Behavior, 1975, 14, 506-522.

9. Kosslyn, S. M. Scanning visual images: some structural implications. Perception and Psychophysics, 1973, 14, 90-94.

10. Kosslyn, S. M. Information representation in visual images. Coguitive Psychology, 1975, 7, 341-370.

11. Kosslyn, S. M. and Pomerantz, J. P. Imagery, propositions and the form of internal representations. Cognitive Psychology, 1977, 9, 52-76.

12. Kozlowski, L. T. and Bryant, K. J. Sense of direction, spatial orientation and cognitive maps. Journal of Experimental Psychology: Human Perception and Performance, 1977, 3, 590-598.

13. Millar, S. Spatial memory by blind and sighted children. British Journal of Psychology, 1975, 66, 449-459.

14. Phillips, W. A. and Christie, D. F. M. Components of visual memory. Quarterly Journal of Experimental Psychology, 1977, 29, 637-650.

15. Pylyshyn, Z. W. What the mind's eye tells the mind's brain: A critique of mental imagery. Psychological Bulletin, 1973, 80, 1-24.

16. Siegel, A. W. and White, S. H. The development of spatial representations of large-scale environments. In H. W. Reese (Ed.), Advances in child development and behaviour (Vol. 10), New York: Academic Press, 1975.

17. Thorndyke, P. and Stasz, C. Individual differences in procedures for knowledge acquisition from maps. Cognitive Psychology, 1980, 12, 137-175.

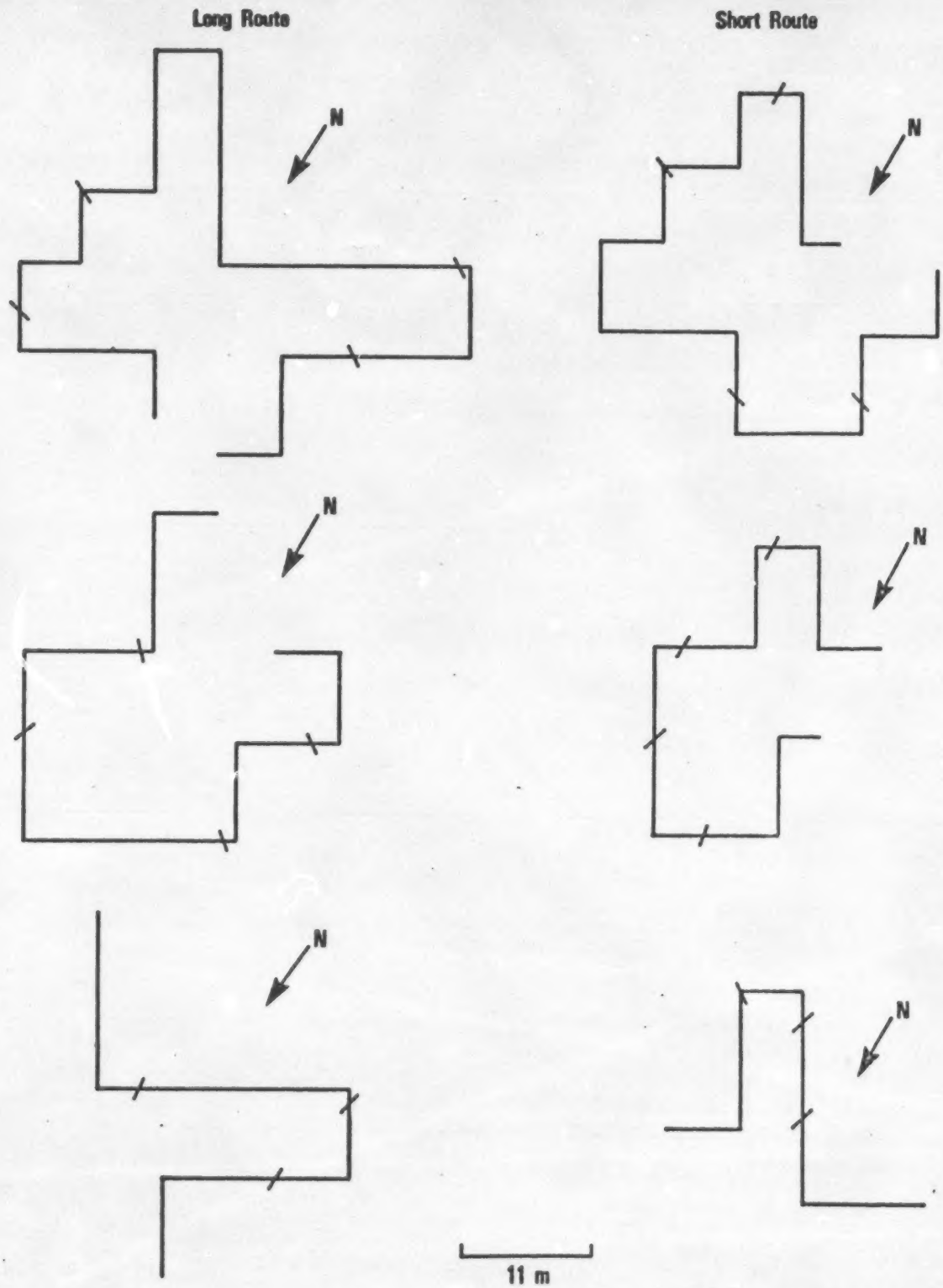

FIGURE 1. A SCHEMATIC REPRESENTATION OF THE SIX ROUTES USED IN EXPERIMENT 1, FROM TOP TO BOTTOM, FOR 13, 8, AND 4 TURNS. THE SPATIAL LOCATIONS ARE IDENTIFIED BY HATCH MARKS.

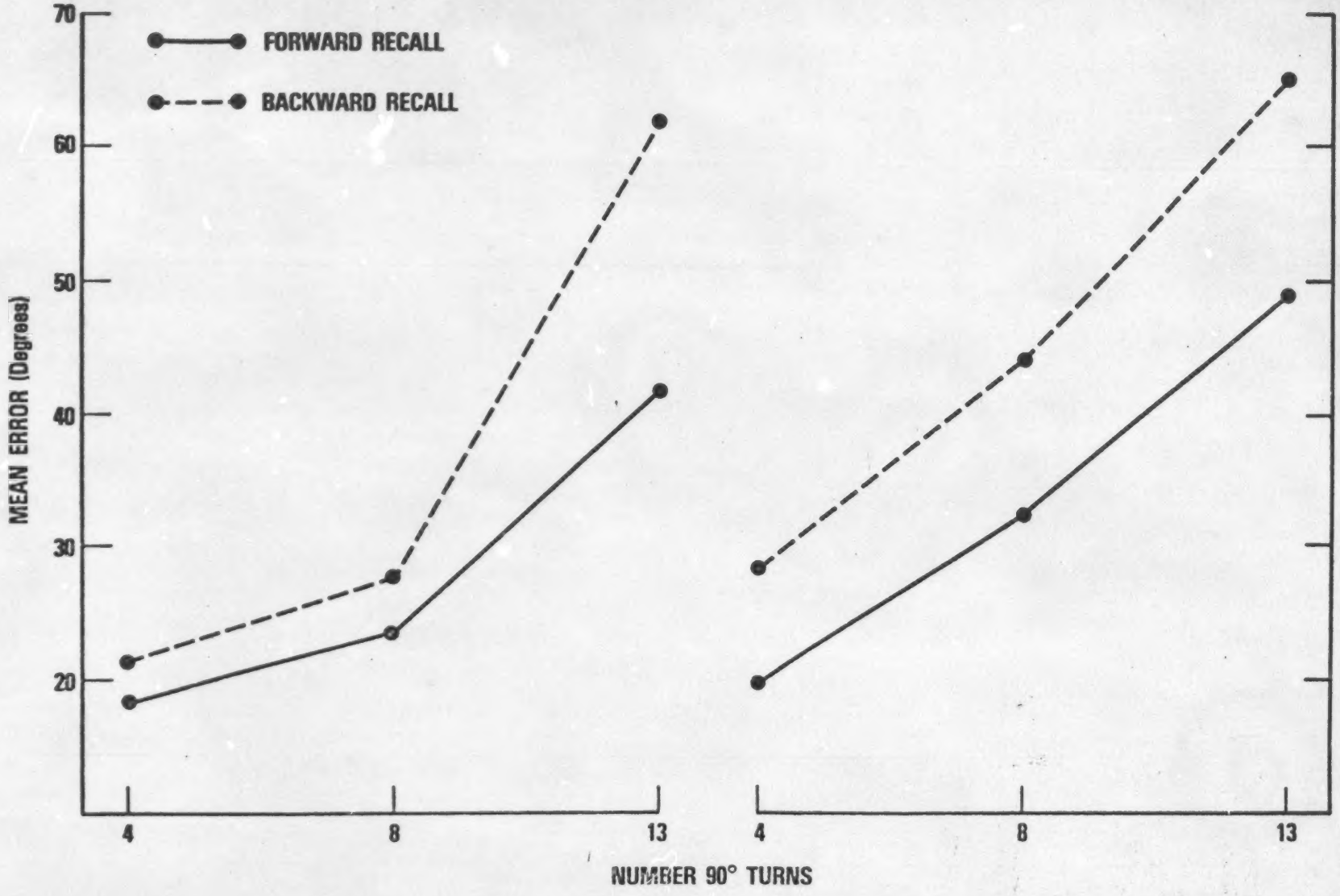

FIGURE 2. MEAN POINTING ERROR UNDER FORWARD AND BACKWARD RECALL, FROM LEFT TO RIGHT, FOR SPATIALLY SKILLED AND UNSKILLED SUBJECTS.

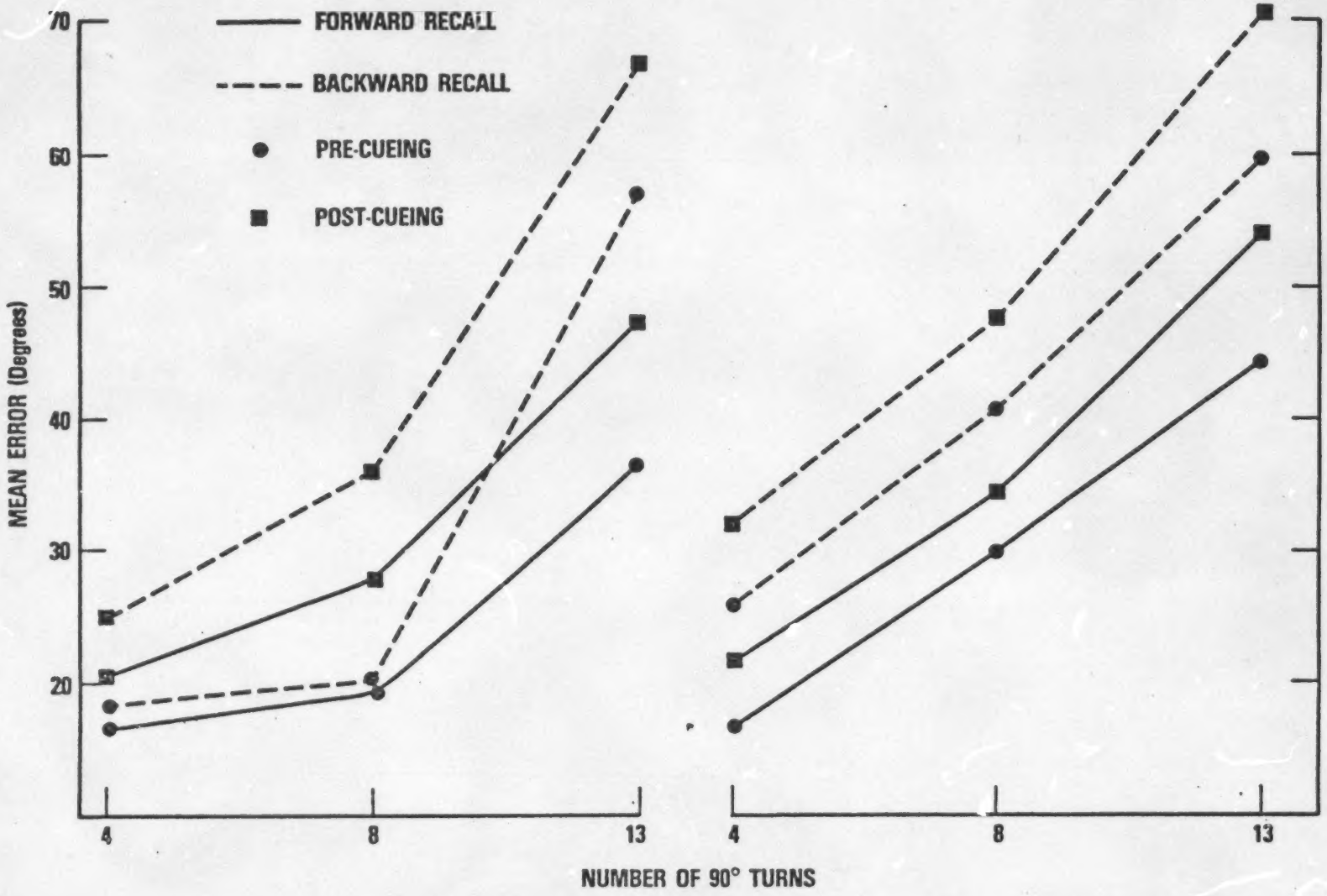

FIGURE 3. MEAN POINTING ERROR IN PRE-AND POST-CUED CONDITIONS UNDER FORWARD AND BACKWARD RECALL, FROM LEFT TO RIGHT, FOR SPATIALLY SKILLED AND UNSKILLED SUBJECTS.

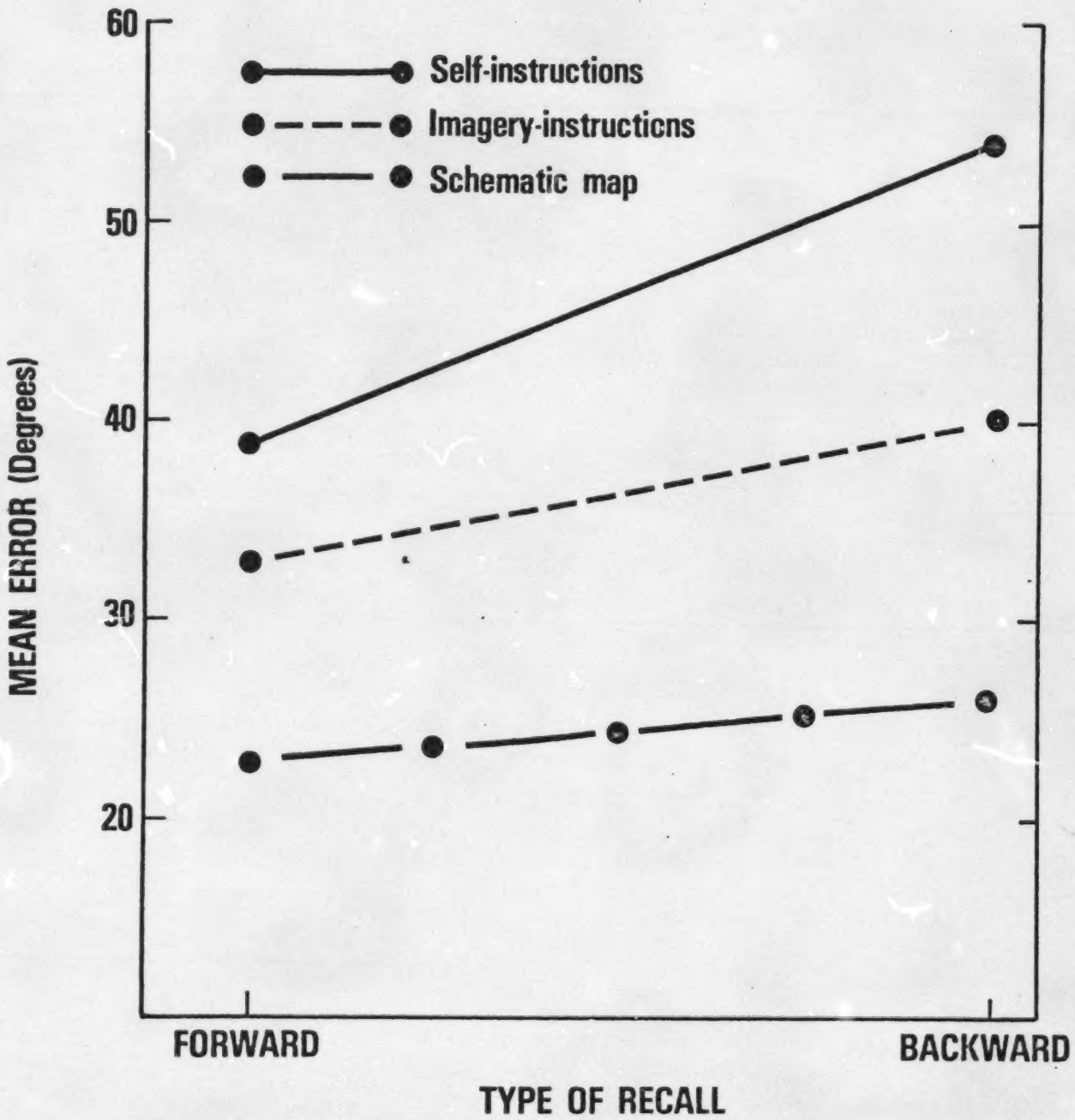

FIGURE 4. MEAN POINTING ERROR FOR THE TWO WORST SUBJECTS UNDER THREE INSTRUCTIONAL CONDITIONS: SELF-INSTRUCTION, IMAGERY INSTRUCTION AND A SCHEMATIC MAP.

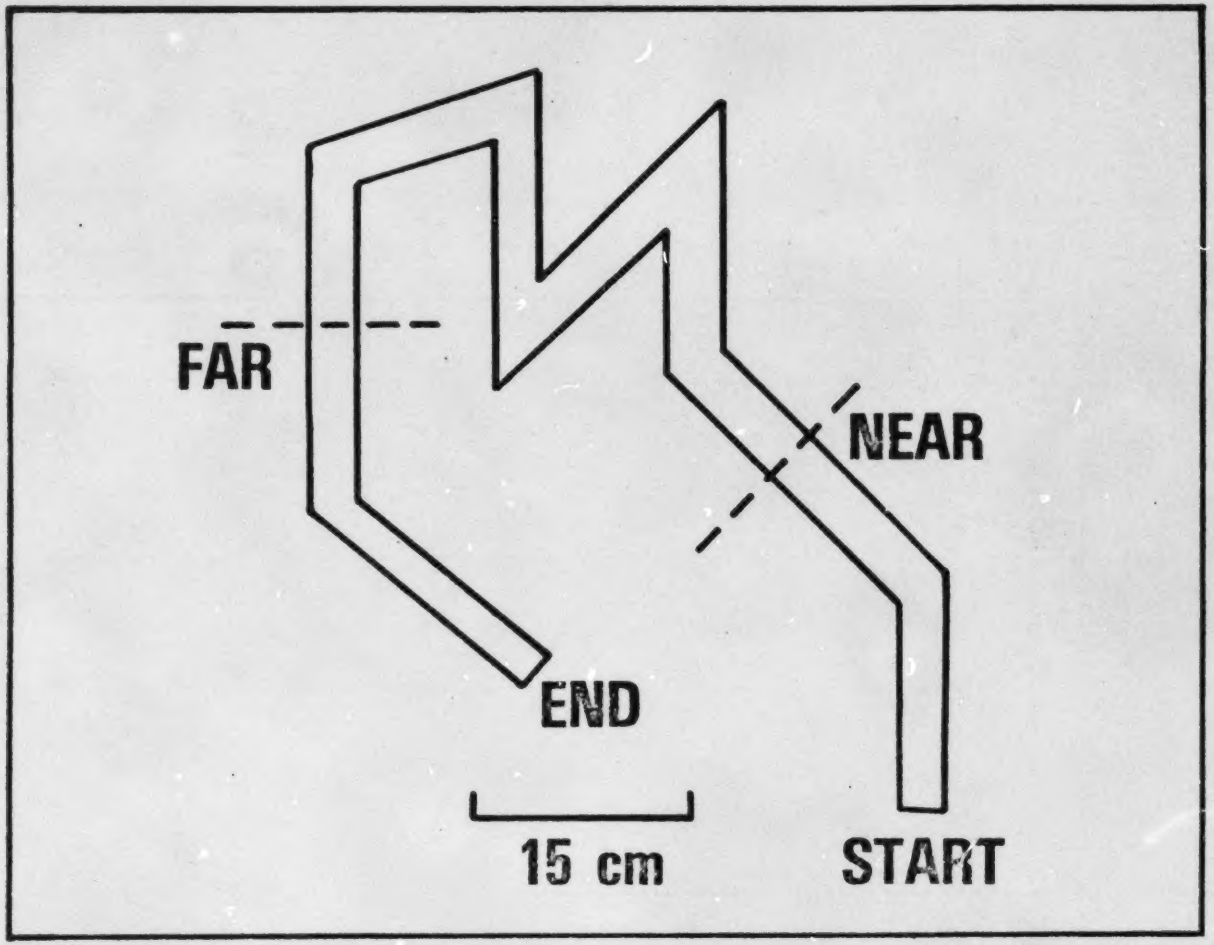

FIGURE 5. THE EIGHT-SIDED SPATIAL DISPLAY USED IN EXPERIMENT 2. THE SPATIAL POSITIONS ARE IDENTIFIED ON THE DISPLAY BY HATCH MARKS. (ADAPTED FROM MILLAR, 1975).

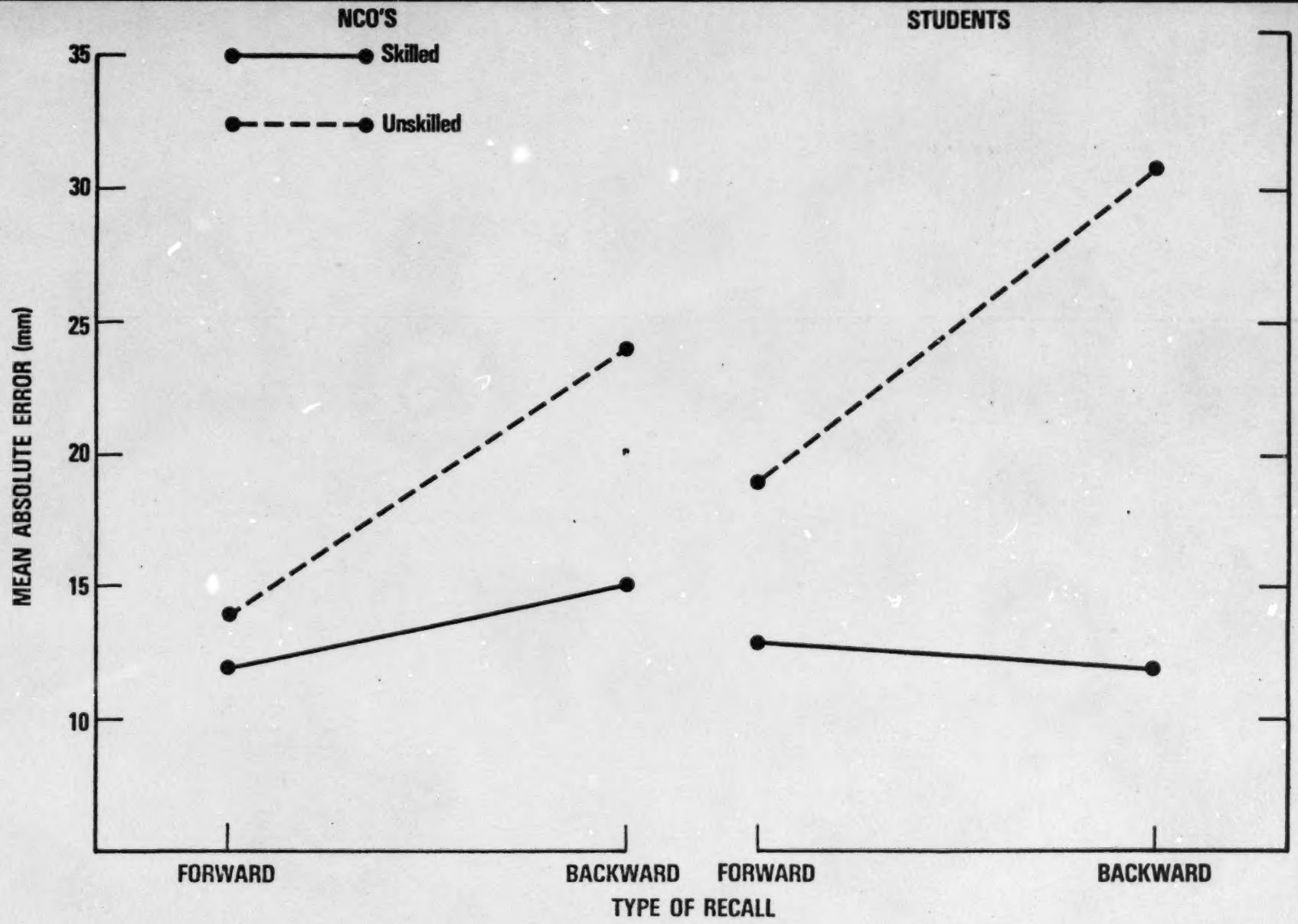

FIGURE 6. MEAN ABSOLUTE ERROR (mm) FOR FORWARD AND BACKWARD RECALL FOR SPATIALLY SKILLED AND UNSKILLED SUBJECTS.

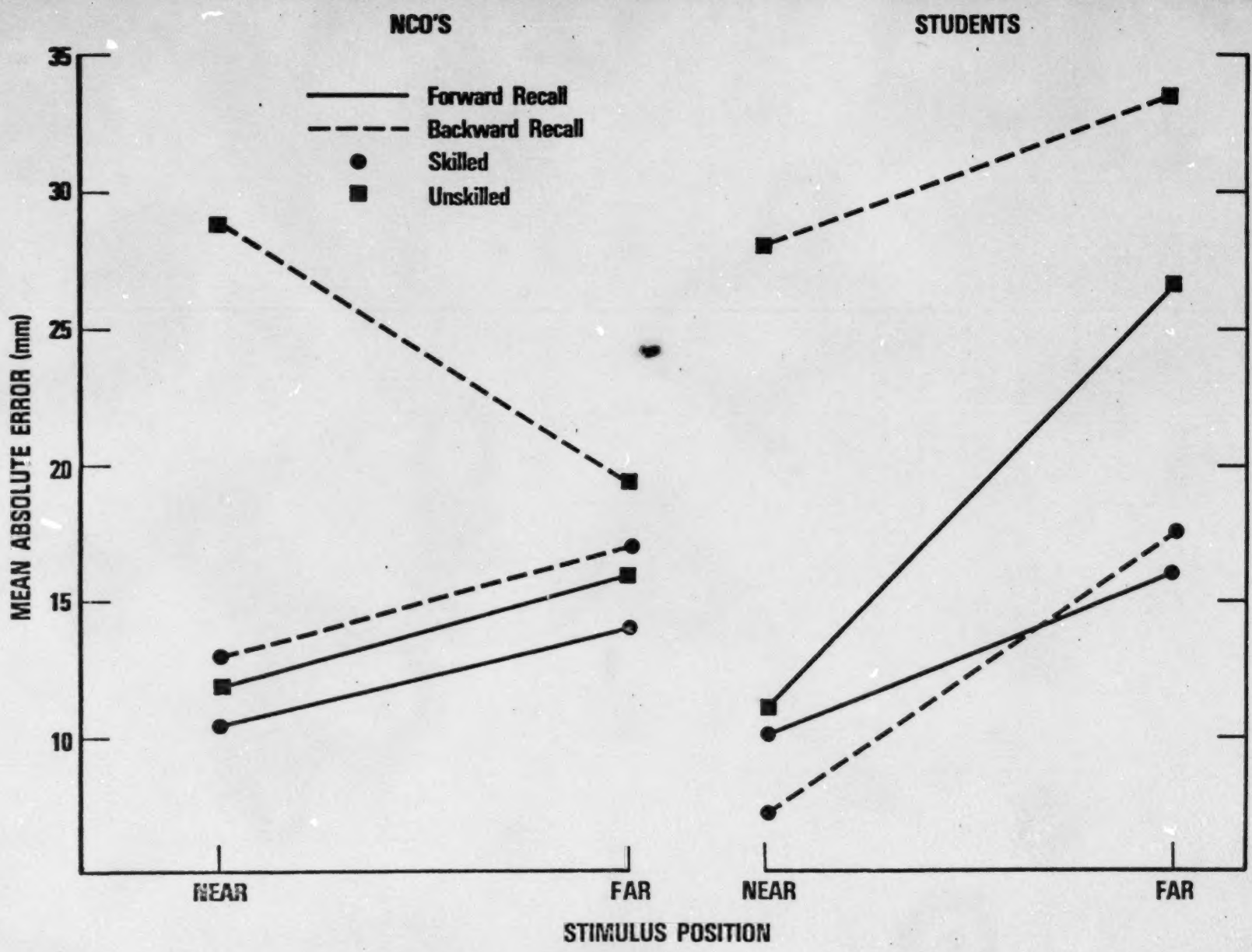

FIGURE 7. MEAN ABSOLUTE ERROR (mm) FOR NEAR AND FAR POSITIONS IN FORWARD AND BACKWARD RECALL, FOR SPATIALLY SKILLED AND UNSKILLED SUBJECTS.